Cognitive Artifacts' Implications for Health Care Information Technology: Revealing How Practitioners Create and Share Their Understanding of Daily Work

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Abstract

Objectives: Our research seeks to discover the deep structure of practitioner cognitive work. The purpose is to improve the capture, use, and sharing of information related to clinical planning and management at the clinical unit level, which shapes the unit's work and leads to success or failure of patient care. **Methods**: Field observation, informal interviews, artifact analysis, and controlled study were used to examine the creation and use of shared cognitive artifacts, particularly the operating room schedule, as a way to reveal individual and group cognition. **Results**: This work shows how practitioners anticipate, plan, and accommodate demands for care in a setting (such as a surgical suite) with constrained resources and variable uncertainty. It also demonstrates how practitioners create and maintain cognitive artifacts that represent the day's work. **Conclusions**: The study of cognitive artifacts can identify critical features of the acute care work domain and the deep structure of individual and team cognition, reveal the nature of artifacts, show these artifacts' role as a part of the team's distributed cognition, and suggest opportunities for the development of computer-supported artifacts.

Introduction—the nature of technical work

The work of health care practitioners includes diagnostic and therapeutic interventions that enable a practitioner to understand and, in many cases, influence the patient's future course. These cognitive tasks are the subject of intense study[1] and are supported by a large body of knowledge, a tradition of training, and many artifacts. There is more to care, though, than just interventions. Patient care also requires practitioners to perform a wide variety of tasks that are collectively described as *technical work.*[2] Technical work includes those activities and situations that engage the myriad details of real-world work settings. They include the prosaic but important issues of resource availability and allocation, the social and organizational structures that promote or inhibit work, the regularity of work situations, and the current and expected tempo of activities. These activities are so mundane that many practitioners consider them the "background noise" of the workplace. Yet technical work is not trivial. It surrounds patient care and encompasses the ordinary details that influence decisions and actions (Figure 1).

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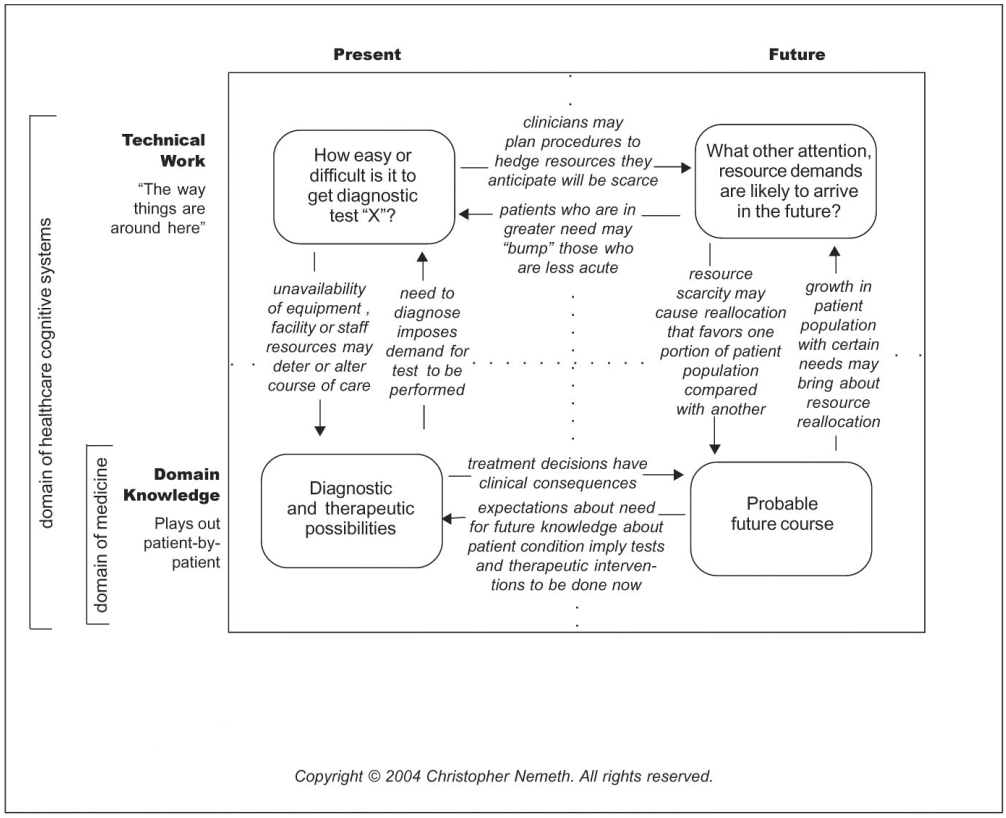
Figure 1. Domain knowledge and technical work are contingent on each other



For example, whether a patient undergoes a particular test depends not only on whether the test is useful in diagnosis, but also on whether the staff, equipment, and facility resources needed are available now; how long the queue for those resources is; whether other suitable tests might be available earlier; and how long it will take to arrange transportation for the patient to the place where the test is to be conducted. Each factor matters individually. The factors also interact, forming a dense network of constraints and affordances.[3] Technical work is what practitioners do as they confront these factors and their interactions. Success or failure at technical work has clinical consequences for individual patients as well as implications for the organization itself. Technical work influences the availability and allocation of resources, creates and removes bottlenecks, and couples and decouples parts of the organization. Practitioners anticipate and coordinate their workflow based on available resources and expectations about the future.

This article describes a research approach to understanding technical work that relies on the analysis of cognitive artifacts and their role in distributing cognition within the workplace. The specific target of this research is the coordination of work in a suite of operating rooms. The research employs a variety of methods to identify and describe the cognitive tasks that confront health care workers. In doing so, it results in a deeper understanding of technical work and how processes of care create or erode patient safety.

Technical work in groups

Health care work is a complicated, high-stakes, time-pressured process. The activities of a group (or "suite") of operating rooms require different resources, types of knowledge, and professional performance. The activities are accomplished in part by distributing work and cognition across people and artifacts. *Distributed cognition*[4] is the shared awareness of goals, plans, and details that no single individual grasps. By distributing cognition, individuals cultivate a mutual awareness and an understanding that allows them to collectively accomplish their individual and shared goals.[5] The sharing and coordination that distributed cognition provides is more than useful. It is an essential part of work in groups.

Much of the coordination of work relies on the development and use of cognitive artifacts.[6] These are objects such as schedules, display boards, lists, and worksheets that are used to hold and represent information that is related to states, conditions, dependencies, and processes. Artifacts are particularly useful for distributing this information through time and among locations. As such, they represent a form of distributed cognition and offer researchers a means to understand the nature of acute care cognitive work. The effort that is expended to develop and maintain cognitive artifacts, and the reliance that practitioners place on them, demonstrates the value that the artifacts have for the work world.

There are many actors in operating rooms, including surgeons, anesthesiologists, technicians, nurses, pharmacists, engineers, and others. Many of these actors come and go. A surgeon, for example, may come into the operating rooms, perform a single procedure, and leave. In contrast, anesthesiologists and surgical nurses are in constant attendance in operating rooms. It falls to representatives from these two groups to coordinate the activities of the operating room suite. Management of an operating room suite is far more complex and conflicted than most outsiders appreciate. The expensive resources that are involved in their daily activities are in chronically short supply. The inherent uncertainty in the course of illness and of surgery makes the control of these settings difficult.

In the United States, the operating room suite is typically managed by two individuals: an anesthesia coordinator (AC) and a nursing coordinator (NC). These two roles represent the most important resources needed to conduct surgical procedures: anesthesia staff and nurses. Both coordinators seek to manage the daily schedule of cases and to handle the inevitable emergencies that occur. They keep track of the status of procedures in progress, anticipate resource shortfalls and excesses, and work to keep the functions of the operating room suite running smoothly. To do that, they rely on the pager or phone, a variety of cognitive artifacts, knowledge of surgery and disease, and deep knowledge of the processes and people involved to accomplish their tasks.

Cognitive artifacts are found throughout the operating room suite, and they clearly play important roles. Mediating this collective work requires cognitive artifacts that can be "shared as a way of maintaining an overview of the total

activity."[7] One artifact is central and prominent in coordinating the suite itself: *the master schedule*.[8] The master schedule, which may be referred to locally as "the board" or "the schedule," is a list of the suite's scheduled surgical procedures for the day, organized by operating room. Master schedules are ubiquitous: every operating room suite has one, and the coordination work for the suite revolves around this artifact. Virtually all of the approaches that are available for coordination require reference to this artifact.

Understanding how coordination works

Two themes guide this research into acute care cognition. The first is to understand the work domain as a complex, high-hazard, time-pressured, interruption-driven environment. The second is to understand acute care team management strategies such as anticipation, hedging and husbanding resources, and making trade-offs. Artifacts reveal information about both themes. Nemeth[8] demonstrates how the study of cognitive artifacts—including the availabilities sheet, master schedule, operating room (OR) graph, and OR board—provides a means to understand how acute care teams plan and manage the balance between care demands and staff resources.

Figure 2 shows how this research used artifacts to study cognition at the unit level, along two dimensions. One dimension, on the left side of the figure, shows how an artifact evolves into a plan and then becomes the reality of a daily schedule. The other, on the right side of the figure, uses the artifact as a highly encoded representation that describes the nature of this complex work domain. While the first approach shows how the artifact is created, the second approach uses the artifact to reveal the basis for its creation. This design meets many of the criteria for qualitative research[9] by incorporating observation, informal interview, and artifact analysis to depict the actual nature of human behavior with cognitive artifacts.

The first approach involved the study of how anesthesia coordinators plan the daily schedule for the OR unit and outpatient clinic. Coordinators were invited to develop a schedule while being recorded on videotape. The coordinators were presented with an actual scheduling task and used copies of the original artifacts to develop an actual schedule. Cognitive activity analyses were performed using transcripts of the verbalizations, the annotated artifacts, and review of session recordings. The analysis produced a formalized performance description[10] for anesthesia coordinators that documented the relationships between the cognitive work that the coordinator performed and the artifacts that were used to support it (Figure 3).

The second approach studied the acute care team through direct observation and interviews with dozens of nurses, nurse coordinators, anesthesiologists and nurse anesthetists, and anesthesia coordinators. Field notes captured insights about the ways that team members use cognitive artifacts to manage their daily activity. A detailed examination of the scheduling artifacts and their use showed the ebb and flow of team activity as it played out through the day. Twelve case

Figure 2. Methods to research acute care cognition

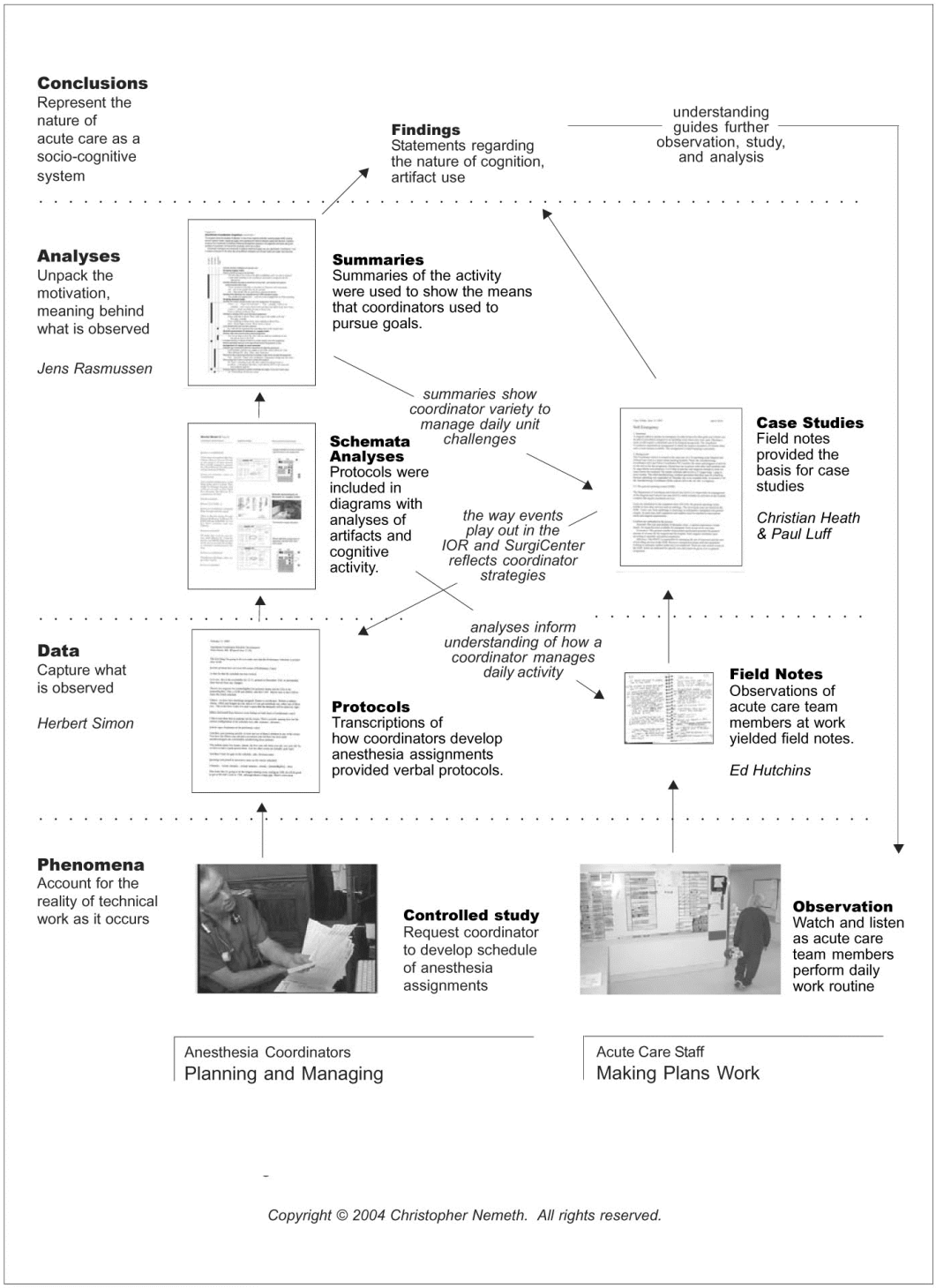
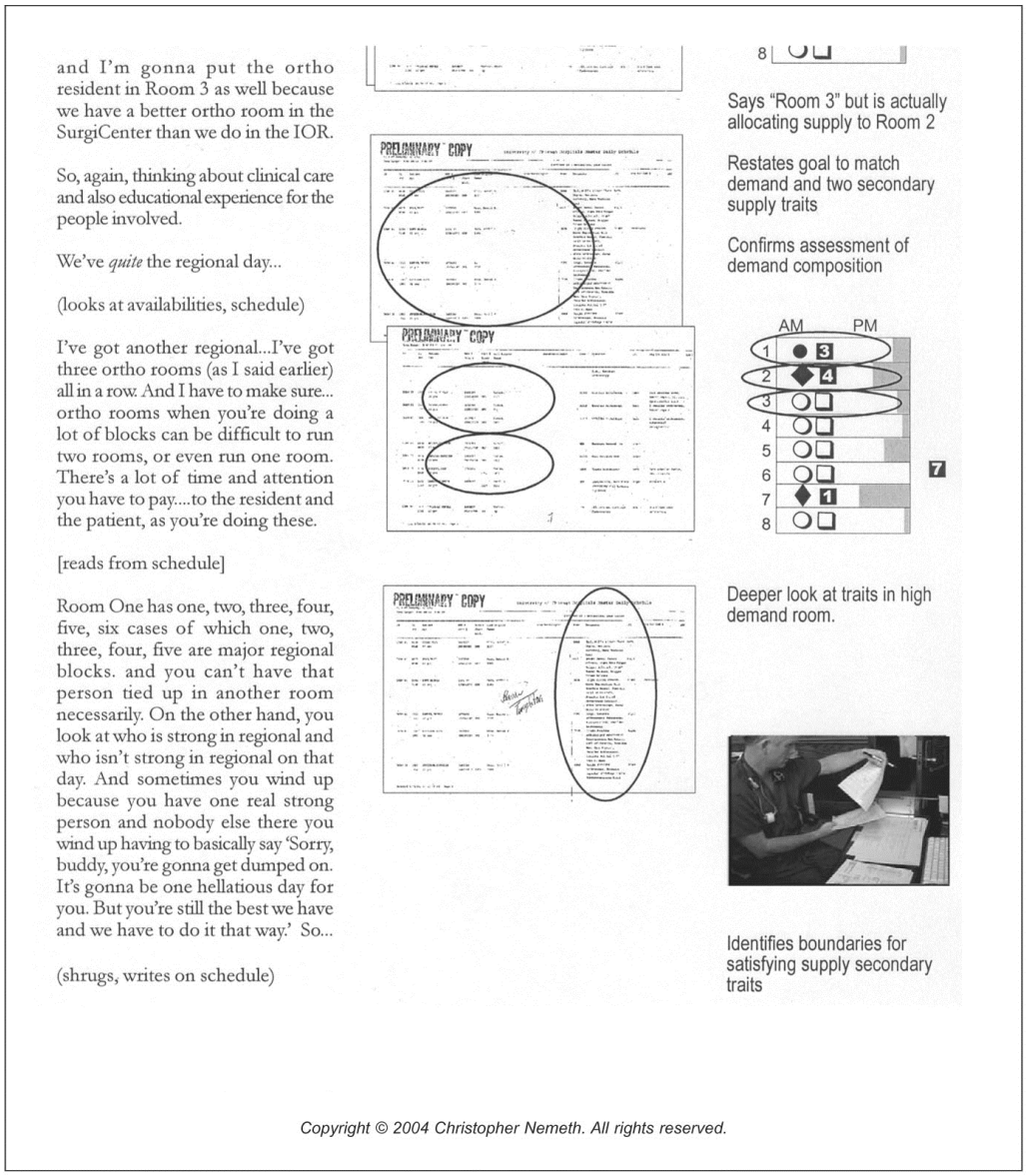


Figure 3. Sample schemata analysis of coordinator schedule writing



studies were created to synthesize the observations, comments from informal interviews, and analysis. Each study described the activity that was observed and related it to the schedule. Informal review by other practitioners added to our confidence that these cases represent the circumstances that confront coordinators and the approaches they take in coping with the demands that result.

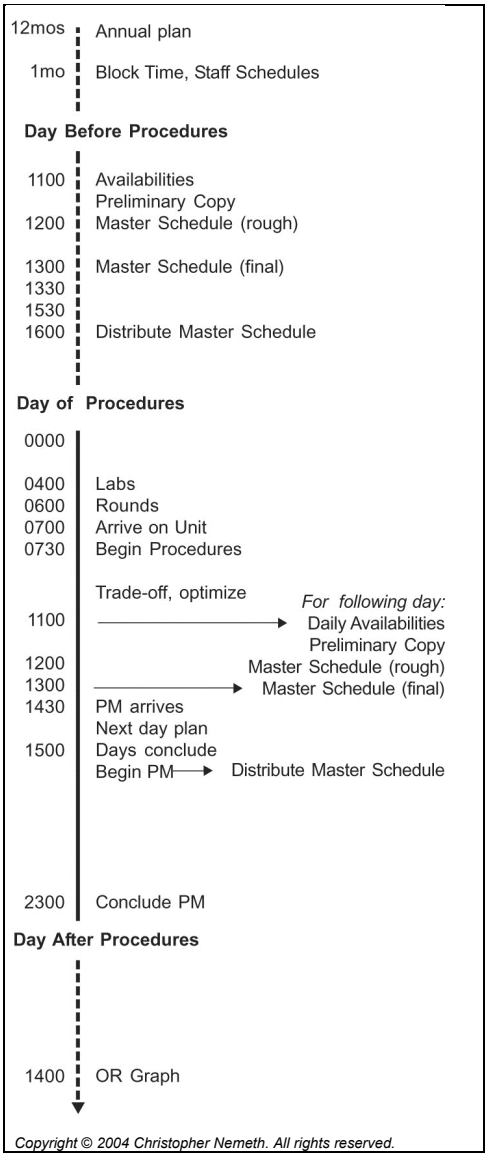
Operating in the operating room suite

Each day's activities in the operating room suite are the product of the coordinator's efforts to create a feasible future, as well as of team member efforts to make the day a success despite the many obstacles that emerge.

Preparing the way for success

Plans for each day's procedures start a year beforehand. Figure 4 shows the evolution of anesthesia department assignments for 1 day of procedures. All departmental plans come together over 3 days as the various workers develop, complete, and execute the work that is described by the master schedule. Each plan is developed in parallel and leads to publishing of the day's master schedule 18 hours before that day's work begins. The anesthesia coordinator locks in the final assignments master schedule at around 11 a.m. each day, prescribing the cycle for the next 24 hours. The process continues even after the day's work is done, as the actual procedures that were accomplished are translated into the OR graph on the next day. Nursing, equipment technicians, and surgeons also have similar planning artifacts that are not shown here.

Figure 4. Schedule time line



To make assignments, the anesthesia coordinator seeks to satisfy a variety of competing needs, to anticipate the various uncertainties that necessarily accompany work in this setting, and to make these uncertainties manageable. Each proposed schedule is unique, and the variety of needs and constraints are different from day to day. No two coordinators will make the assignments in the same way. Even so, the differences in how each individual writes a schedule are small compared with the similarities among the underlying drivers that determine the quality of a set of assignments: demand, economics, efficiency, and teaching.

Demand. The type and number of demands varies. Some of the demands are represented in the preliminary schedule, and these can be handled directly. There are also unpredictable but expected events that can intrude.

Economics. The maximum number of procedures performed generates the greatest amount of revenue for the surgeon and the hospital. But it is not only the hospital that makes money from the activities of the day. Each surgical department will be compensated for procedures performed. Dividing the work equitably is important both when the practitioners are paid by the procedure and also when they are salaried. The work of an operating room is, minute by minute, the most valuable and expensive anywhere in the hospital.

Efficiency. The anesthesia department is responsible for managing the use of resources and the cost of providing anesthesia services. It is important to use each resource efficiently.

Teaching. Simply matching the best possible resource to the demand is not sufficient in a teaching setting. Students and residents need opportunities to learn, and these learning experiences are less efficient ways of delivering care. Education and learning are beneficial in the long term, but almost always inefficient in the short term. The coordinator must balance these competing goals without sacrificing one to achieve the other.

Inside this context, what makes writing a schedule easy or difficult? Both ease and difficulty flow from the nature of demand for care (volume, acuity, composition) and of the resources to meet it (availability, flexibility, resilience).

Demand volume. The number of procedures correlates with the required number of staff in the operating rooms. On “heavy” days there are few degrees of freedom; on “light” days, the coordinator has greater flexibility, perhaps enough to allow staff to work away from the unit on research or to take personal time.

Demand acuity. Urgent and emergent cases must be treated. The greater number of acute cases, the greater the pressure to treat them. Emergent cases interrupt the schedule, and having more of them produces greater schedule instability.

Demand composition. Specific demands may have local effect on certain qualifications. An OR scheduled for a long, complex procedure offers few opportunities for rearrangement, while a room with multiple short procedures can be counted on to become available to handle emergencies at intervals.

Resource availability and flexibility. Staff members work in shifts, so the shift boundaries determine the available staff. The planning process needs to account for the varying numbers of staff available across these boundaries. Certain staff members are capable of doing certain tasks, but staff members are not interchangeable and may even have preferences for particular types of work.

Under normal circumstances, the person who makes out the schedule for the next day is the anesthesia coordinator for that day. The process of making the schedule requires familiarity with details of demand and supply. This experience helps the future coordinator to develop a mental map of the operational demands that may last through the day's activity. The written schedule is the best plan that can be created up to a few hours before the day begins (around 6:30 a.m.). As the saying goes, though, no plan survives contact with the enemy. The schedule is a formal statement of expectation about how the day will play out. However, the contents of the schedule are a set of provisional resource commitments that will need to be amended in order to meet the demands of the day as they evolve.

Making it work on the day of surgery

The master schedule is posted in the corridor that leads to the operating room suite. This is the center for the operating room traffic, and the schedule's location ensures that it is available for every worker to see. The annotations and changes that are made to it are public. People literally and figuratively gesture to it throughout the day. The arguments that occur in the OR frequently occur near the place where the schedule is posted, as the issues that it calls attention to are frequently contentious and contended.

The following brief scenario offers a glimpse of how the coordinators use the schedule to manage the operating room suite. It is the middle of the afternoon, about 2:30 p.m. The coordinator is anticipating the "end game" for the current day by estimating when cases that are underway will finish. He also assesses the effect that their completion times will have for the many cases that have yet to begin. Eventually the coordinator will leave and turn the running of the day over to the night call anesthesiologist.

The coordinator points to a location on the master schedule to identify a particular resident. "He was here on Saturday and Sunday, doing livers. So if you can, get him out early." He then turns to the cases that remain on the schedule for the day. "Room A2 is a debridement skin case. Two hours. Should be out by 5:00." He checks his pager for a message he has stored on it. "The tracheostomy in A3 should be out by 3:30."

The nurse coordinator reads aloud from the list of cases yet to be done. The night call anesthesiologist writes a tally on the schedule board in marker, including an estimate of end time for each operating room. There is a nursing shift change at 3 p.m. and another at 7 p.m., which reduces the number of operating rooms that can be staffed; so the end times are a way of projecting the potential for staff shortfalls.

The anesthesia coordinator refers to one of the procedures listed on the schedule and says to the nurse coordinator, “I’m getting tired of that.” “[name], don't call that case. They should have done that nephrostomy tube by now.” The anesthesia coordinator calls on the phone, “Don’t send for the case in B15. We’ve been waiting for an hour for that case.” The anesthesia coordinator and night call anesthesiologist continue to confer over the schedule on the OR board for a minute and the phone rings. The coordinator picks up the call and we hear one side of the conversation: “Yeah, you can either cancel it, hold and reschedule it, or wait until later. [pause] Why didn't they do it earlier? [pause] No. I’m closing the room. My staff leaves at 3:00. We’ve been waiting for 45 minutes. [pause] I’m not blaming you. [pause] I know you move fast. I’m trying to help you out as much as I can. We’ve been waiting for an hour. When did the patient show up?”

A nurse stops by and holds out a piece of note paper with writing on it. “Can we start this next case?” The coordinator shakes his head, “No. I have nowhere to put patients. They’re backed up in the recovery room.” The nurse responds, “If we start now we’ll be done in 4 hours.” The coordinator replies, “I have patients who are waiting in the rooms now with no beds.”

The overhead public address system calls for a vascular surgeon and vascular clamps to room A3. The nurse coordinator takes a call and says to the anesthesia coordinator, “They need a vascular tech in A3. They think they hit the carotid.”

The night call anesthesiologist adds a few notations indicating rooms that have further cases scheduled. The coordinator draws a bracket to enclose one set of cases. “You may not do these,” he says. “If you can do one, do this. He’s fast.” [Referring to the surgeon.] The coordinator changes the projected end time for the procedure in A3 from 3:30 to “?”.

As the evening shift progresses, further notation in marker will refine the information that is related to each case. By 7 p.m., the night shift has taken over, and only two rooms are in operation. (Adapted from Nemeth,[8] pp. 225–7.)

During the day, the master schedule is a dynamic artifact. People make reference to it frequently because it embodies the important information related to the conduct of technical work in the domain. Critical issues of staffing and the order of cases start playing out within and through the artifact, which is carefully controlled and treated with respect. It encodes the critical bits of information, such as the precedence of cases, that are essential to managing the work of the day. As this scenario shows, it does not produce certainty about what will happen. Instead, it is a platform that is used to conduct the work of coordinating the OR suite.

Workers expend effort to maintain the artifact and to keep it current. They do so because it is a valuable part of their work world, distributing cognition across time and individuals in order to make it possible to get through the day. There are specific properties of the artifact that make it useful in this context. It is an *accurate* representation of the current state of work. It is an *efficient* representation that encodes useful information in ways that make it easy for users to understand important data and relationships between data. It is continuously *available* for use when needed. It is *informative* about the circumstances of

interest to the team and also clear and *unambiguous.* It is *malleable* and available to be manipulated by its owners.

The future of cognitive artifacts and technical work

As described above, cognitive artifacts are physical objects that acute care team members create and use to manage their work environment. Studying these artifacts reveals the deep knowledge that team members have used to create them.

The goal of patient safety research is to discover the factors that shape the work world and lead to success and failure in patient care. The research approach that is described here is a rich source of insight into the technical work of individuals and groups in health care. The cognition of those who work in the operating room suite is distributed in order to strike, and manage, the balance of constrained resources with the continually changing demand for services.

Cognitive artifacts can be used to learn about the work that they have been designed to support. For Hutchins,[6] "cognitive artifacts are involved in a process of organizing functional skills into functional systems." This amounts to "a category of processes that produce cognitive effects by bringing functional skills into coordination with various kinds of structure." The study of a cognitive artifact yields insight into the nature of the artifact itself as well as insight into the technical work situation and intentions that the artifact represents. Focusing on artifacts provides an opportunity for researchers to identify critical features of the domain and work situation.

Artifacts are highly encoded representations of what matters in this domain. Artifact encoding conveys the information in a compact, efficient manner. The content is inherently connected to what is meaningful in the domain. This is because cognitive artifacts typically are used to support important, difficult activities. In addition, the work that the artifact is designed to support can also be improved by making a better artifact. Better information design or improved use of information technology (software) can make technical work more enjoyable, more efficient, and more reliable.

The physical cognitive artifacts that we have studied show how an organization seeks to reduce uncertainty so that workers can manage the unmanageable. Artifacts show how practitioners apply their expertise to the creation and management of a plan in order to perform a complex set of procedures. Artifacts also reveal how real-world demands undo the coordinators' intentions and force resources to be reorganized to satisfy the unpredictable flow of urgent needs. Because they are useful to practitioners, artifacts make it possible for the researcher to focus on the most meaningful and aspects of a complex technical work setting.

Our research has studied the creation and use of shared cognitive artifacts, particularly the operating room schedule. This work shows how practitioners anticipate, plan, and reconcile constrained resources with variable, uncertain demand for care. It also demonstrates how practitioners create and maintain

cognitive artifacts that represent the day's work. This reveals the complex moment-to-moment planning and management activity in this complex, demanding setting, and it provides high-level views of team work.

Conclusions: reaching for discovery

Practitioners are not passive recipients of the plans made by others, but active participants who adapt the plans and react to situations continually throughout the day. Their ability to create success in spite of obstacles comes from multiple factors: long experience with the technical work that they and others are carrying out, a variety of hedges against uncertainty, and their capacity to redirect the people and resources in their world to take care of the new situations that arise. To do this they create, refer to, annotate, modify, update, and correct the primary cognitive artifact—the master schedule. This schedule serves as the funnel-point for many artifacts that are created and manipulated over the weeks and months that precede its creation.

Through the study of cognitive artifacts, researchers can identify critical features of the acute care work domain and the deep structure of individual and team cognition. Such study also reveals the nature of physical artifacts, shows their role as a part of the team's distributed cognition, and suggests opportunities for digital artifact development.

Rather than simply mimic existing cognitive artifacts, useful information technology (IT) applications will reflect this deep understanding, provide new problem representations, and make work domain constraints explicit. IT has much in common with artifacts. In fact, computer-supported artifacts are often modeled as iconic representations of physical tools. Yet, without research, these systems are necessarily blind to the sophisticated, refined interactions that practitioners have developed to perform complex work.[11] Understanding the origin and nature of artifacts relies on deep and sustained observation of the groups and activities they support in order to derive their meaning. The method that is described in this paper provides a basis to develop and evaluate future IT systems in health care.

Future IT artifacts will need to succeed on two levels. They will first need to incorporate the kind of research approach described here to overcome the shortcomings of computer-supported systems that simply mimic physical artifacts. Second, they should be designed to add value beyond the limitations of physical artifacts to better support practitioners' needs to improve patient care and resource use.[12] Within the context of coordinating an OR suite, several classes of support are likely to prove useful: prompting, speculation, consequence assessment, and value-based decisions.

Prompting—Computer-supported artifacts might survey information in the distributed cognition for gaps and inconsistencies that would otherwise go unnoticed. Bringing such item(s) to the schedule writer's attention for consideration would enrich and improve the cognitive work.

Speculation—Computer-supported artifacts can make it possible for coordinators to speculate about possible courses of action, develop multiple trial solutions, and then choose among them. Providing multiple options for evaluation would make their consideration more thorough. Aiding temporal reasoning, such as anticipation of the case end times in relationship to shift boundaries, is likely to be useful.

Consequences—The application of evaluation criteria to potential courses of action could make it possible to display the consequences of choices. For example, a system might show how billing could be increased or how costs could be minimized by opening one room or closing another, or by allowing coordinators to compare notional schedules.

Value-based decisions—Computer-supported artifacts can be used to develop templates of schedule-planning strategies. Coordinators can review and employ a template that best matches their values and preferences. Such templates can capture scheduling expertise and make it available for use by others, expanding best-schedule-writing practices beyond a single individual. Study of template use through time might open the way to insights about coordinator training and the development of schedule models to ease coordinator work loads.

The research methods that have been described here get at the nature of practitioner behavior, including practitioner goals and the strategies employed to achieve them.[13] Ethnographic methods make it possible to evaluate new cognitive artifacts by determining the fit between an artifact and the work domain for which it is intended. Those who seek a way to understand the cognitive work in a domain will need to use such an approach in order to develop IT that is authentically suited to practitioner needs.

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